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# *DEET insect repellent: effects on thermoregulatory sweating and physiological strain*

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# DEET insect repellent: effects on thermoregulatory sweating and physiological strain

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**Abstract** Insect repellents (e.g. *N,N*-diethyl-*m*-toluamide or DEET) applied to the skin can potentially interfere with sweat production and evaporation, thus increasing physiological strain during exercise-heat stress. The purpose was to determine the impact of 33% DEET lotion on sweating responses, whole body thermoregulation and thermal sensation during walking exercise in the heat. Nine volunteers (2 females, 7 males;  $22.1 \pm 4.9$  years;  $176.4 \pm 10.0$  cm;  $79.9 \pm 12.9$  kg) completed 5 days of heat acclimation ( $45^{\circ}\text{C}$ , 20% rh; 545 watts; 100 min/day) and performed three trials: control (CON); DEET applied to forearm (DEET<sub>LOC</sub>, 12 cm<sup>2</sup>); and DEET applied to ~13% body surface area (DEET<sub>WB</sub>). Trials consisted of 30 min walking (645 watts) in  $40^{\circ}\text{C}$ , 20% rh environment. Local sweat rate (SR), onset and skin wettedness were measured in DEET<sub>LOC</sub>, and heart rate (HR), rectal temperature ( $T_{\text{re}}$ ), skin temperature ( $T_{\text{sk}}$ ), RPE, and thermal sensations (TS) were measured during DEET<sub>WB</sub>. No differences ( $p > 0.05$ ) were observed between DEET<sub>LOC</sub> versus CON, respectively, for steady state SR ( $1.89 \pm 0.44$  vs.  $2.09 \pm 0.84$  mg/cm<sup>2</sup>/min), SR area under the curve ( $46.9 \pm 11.7$  vs.  $55.0 \pm 20.8$  mg/cm<sup>2</sup>), sweating onset, or skin wettedness. There were no differences ( $p > 0.05$ ) in HR,  $T_{\text{re}}$ ,  $T_{\text{sk}}$ , Physiological Strain Index, RPE or TS between DEET<sub>WB</sub> versus CON. DEET did not impact measures of local forearm sweating and when applied according to military doctrine, did not adversely impact physiological responses

during exercise-heat stress. DEET can be safely worn during military, occupational and recreational activities in hot, insect infested environments.

**Keywords** *N,N*-diethyl-*m*-toluamide · Heat illness · Thermal sensation · Sweat evaporation

## Introduction

Physically stressful military, occupational and recreational tasks are frequently performed in hot and insect-infested environments. In such situations, individuals may voluntarily choose to not apply insect repellents to their skin because of concerns regarding impeded evaporative heat loss, which could increase discomfort and the risk of serious heat illness. One topical insect repellent with the potential to impede evaporative heat loss is *N,N*-diethyl-*m*-toluamide or DEET. Since 1957, the U.S. military has used DEET as the standard skin repellent, as it is effective against a wide variety of disease-transmitting insects, including mosquitoes, flies, fleas, ticks and chigger mites. During training in the field, Marines have reported feeling ‘excessive heat’ after applying an insect repellent lotion (Spaul and Greenleaf 1984). In addition, a National Institute for Occupational Safety and Health (NIOSH) investigation on DEET use by National Park Service workers in the Florida Everglades (McConnell et al. 1986) reported that 12% of National Park employees, reported a loss of sweating sensation after moderate/high DEET application.

When any lotion or cream is applied to the skin, there is the potential for interference with thermoregulatory sweating and evaporation (Connolly and Wilcox 2000; Gabaree et al. 1997; Spaul et al. 1985). Topical skin emollients could either reduce sweat production by

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blocking sweat pores, which would suppress sweat secretion or by forming a barrier to evaporation, thus impeding evaporative heat loss. To our knowledge, only one study has experimentally examined the impact of an insect repellent on physiological responses during exercise-heat stress (Spaul et al. 1985). In addition, only one study examined the impact of a topical skin protectant (TSP) on physiological responses to exercise-heat stress (Gabaree et al. 1997). Spaul and colleagues (1985) reported that an oil-based insect repellent lotion (applied to 80% body surface area, BSA) produced small elevations in core temperature during moderate intensity exercise in a hot-dry environment. Gabaree and colleagues (1997) reported that a TSP that was semi-permeable to water vapor (applied to 22% BSA), also induced small elevations in core temperature during ~135 min of moderate intensity exercise in a hot-humid environment. While this elevation in core temperature was not statistically significant, when extrapolated to 4 h of exercise-heat stress, use of this skin protectant would result in a core temperature increase of 0.5°C.

Taken as a whole, the findings of these studies (Gabaree et al. 1997; Spaul et al. 1985), combined with user reports (McConnell et al. 1986; Spaul and Greenleaf 1984), suggest the potential for DEET to interfere with sweating responses and gross thermoregulation. As the exact formulation of DEET products are proprietary, the impact of such products on sweating responses and whole body thermoregulation are unknown. The purpose of this study was to determine the impact of 33% DEET lotion on local sweating responses, whole body thermoregulation, physiological strain and thermal sensation during moderate-intensity exercise in the heat. We hypothesized that the use of 33% DEET lotion would depress sweating and would increase physiological strain and discomfort.

## Methods

### Subjects

Two females and seven males ( $n = 9$ ) volunteered for this study (age  $22.1 \pm 4.9$  years; height  $176.4 \pm 10.0$  cm; weight  $79.9 \pm 12.9$  kg; body fat  $16.8 \pm 8.6\%$ ). Appropriate institutional review boards approved this study. Before participation each volunteer attended briefings informing them of the purpose of the experiment and possible risks and completed a written informed consent document. Investigators adhered to policies for protection of human subjects as prescribed in Army Regulations 70-25 and US Army Medical Research and Materiel Command Regulation 70-25. The research was conducted in adherence with the provisions of 45 Code of Federal Regulations Part 46.

### Heat acclimation

Volunteers were heat acclimated to reduce variability in physiological responses (particularly sweating), improve exercise-heat tolerance and reduce risk of heat exhaustion (Sawka et al. 1996). Testing occurred in late spring and summer months. Partial acclimation has been observed in warmer months, substantially reducing the magnitude of adaptive changes. As volunteers spent a portion of their day working and training outdoors, partial seasonal acclimatization was presumed thus reducing the length of the heat acclimation protocol. Volunteers performed 5 consecutive days of exercise in a 45°C, 20% RH,  $1 \text{ m s}^{-1}$  wind speed while wearing the Army IPFU (Improved Physical Fitness Uniform) or equivalent (shorts and t-shirt). Treadmill speed was set at  $1.56 \text{ m s}^{-1}$  with a grade of 4% (545 watts). Volunteers walked each day for 100 continuous minutes or until rectal temperature ( $T_{\text{re}}$ ) reached 39.5°C. No fluid was consumed during heat acclimation exercise, but free access to fluid was provided after. Nude body mass was measured each of the five mornings to ensure proper hydration and establish a representative baseline body mass for later use (Cheuvront et al. 2004). Following exercise, subjects were rehydrated within 1% of initial body mass before leaving the laboratory.

During the first day of heat acclimation, body mass was determined for each volunteer using an electronic scale (Mettler Toledo, Model WSI-600, Toledo, OH, USA), followed by measures of body composition. Body density was estimated using skinfold calipers (Lange, Beta Technology Inc., Cambridge, MD, USA) and procedures and equations as described by Jackson and Pollock (1978). Percent body fat was then calculated using the Siri equation (1993). During heat acclimation and all experimental testing sessions, heart rate (HR) was measured every 10-min using a Polar heart rate monitor (Polar a3, Polar Electro Inc, Woodbury, NY, USA). Rectal temperatures ( $T_{\text{re}}$ ) were obtained from a telemetric temperature sensor (VitalSense Jonah<sup>TM</sup> Ingestible Capsule, Minimitter inc., Bend, OR, USA) inserted 8–10 cm (length of gloved index finger) beyond the anal sphincter. This approach yields excellent agreement compared to a conventional rectal probe ( $\leq 0.05^\circ\text{C}$ ) and has been used in other investigations (Ely et al. 2010; Kenefick et al. 2009).

## Experimental design and testing

### 33% DEET lotion testing

After the completion of the 5-day heat acclimation protocol, volunteers took part in two experimental trials and a third trial that served as the control for each experimental

trial. In one experimental trial, local measures of sweat rate, onset, and skin wettedness responses were made with the application of 33% DEET lotion (3M Ultrathon™ insect repellent lotion) on the forearm (DEET<sub>LOC</sub>). In the second experimental trial, measures of gross whole body thermoregulation and thermal sensations were made with 33% DEET lotion spread on various regions of the body according to a specific military model (DEET<sub>WB</sub>). In a third trial, both local sweating measures and whole body thermoregulation and thermal sensation measures were made without DEET application (CON), for purposes of comparison. Each of these trials was separated by 3–5 days and was performed using an incomplete Latin Square design. All experiments were conducted at the same time of day to control for circadian fluctuations in body temperature and other biological variables (Stephenson et al. 1984). Experimental testing was not controlled relative to menstrual cycle phase for the women who participated in the study as both were anovulatory. The mean  $T_{re}$  at the start of testing (time 0) for the two women in the study were 37.1°C in CON, 37.1°C in DEET<sub>LOC</sub>, and 37.2°C in DEET<sub>WB</sub>. Volunteers wore Army Combat Uniforms (ACU) with sleeves up (forearms exposed;  $clo = 1.37$ ,  $i_{m}/clo = 0.34$ ) with running shoes during each of these trials and no fluids were provided during the trials.

In the DEET<sub>LOC</sub> trials, 33% DEET lotion was applied locally to the right arm of four volunteers and the left arm of the remaining five. The mid-point of the ventral forearm, between the antecubital space and the wrist was determined and a  $\sim 12 \text{ cm}^2$  circle was drawn with the mid-point as its center. Using a 3 ml syringe,  $\sim 0.3 \text{ ml}$  of 33% DEET lotion was placed in the circle and a metal spatula was used to uniformly apply the lotion within the area. Volunteers then sat for 30 min while the 33% DEET lotion was absorbed into the skin. In the CON trial, the same procedures were followed except no DEET was applied. After 30 min of seated rest in  $\sim 22^\circ\text{C}$ , volunteers entered the environmental chamber set at  $40^\circ\text{C}$ , 20% RH, and a dew point capsule was fixed on the right or left forearm covering the circled area. A hot, dry environment was selected to eliminate dry heat loss and focus study on evaporative sweating. The vapor pressure difference between moist skin and the ambient air was designed to be kept above the critical value for constant evaporation (Berglund and Gonzalez 1977). Volunteers stood for 20 min and then walked for 30 min ( $1.6 \text{ m s}^{-1}$ , 5.0% grade; 645 watts) on a treadmill windward to  $1 \text{ m s}^{-1}$  wind speed.

In the DEET<sub>WB</sub> trials, 33% DEET lotion was applied to the whole body as directed by the Department of the Army Training and Doctrine Command (Training and Doctrine Command 2007) which describes the application of 33% DEET lotion to be applied “uniformly in a thin coat to exposed skin including face, ears, neck, and hands, also

applied 2 in. under the edges of the ACU, to include wrists, ankles, and waistline”. BSA of the head, neck and hands was determined using a Cyberware three-dimensional head and whole body scanner (Cyberware, Monterey, CA, USA), BSA of the wrists, ankles and waist was determined and expressed relative to the total BSA (DuBois 1916). In DEET<sub>WB</sub>, the BSA covered by the 33% DEET lotion was  $\sim 13\%$  or  $\sim 0.26 \text{ m}^2$  and given the range of BSA of the volunteers tested, the quantity of 33% DEET used ranged from 2 to 6 ml. Following application of the 33% DEET lotion volunteers sat for 30 min in  $\sim 22^\circ\text{C}$ , and then entered the environmental chamber set at the same conditions as the CON and DEET<sub>LOC</sub> trials and performed the same rest and exercise protocol. In the CON trials, no DEET was applied to the body. In all trials, volunteers were instructed to abstain from applying any moisturizer or cream to the skin 24-h prior to testing.

### Measurement description

In the DEET<sub>CON</sub> and DEET<sub>LOC</sub> trials, local sweat rate ( $m_{sw}$ ) of the right or left forearm was measured using automated enclosed ventilated  $15.9 \text{ cm}^2$  capsule (Graichen et al. 1982) containing a Honeywell HIH 4010 humidity sensor and  $2.252 \text{ k}\Omega$  thermistor for temperature measures. Room humidity was measured with a similar capsule hung near the volunteer and dew point calculated. The ventilated capsule was interfaced to a data acquisition system for continuous monitoring and recording. Local sweating rates were calculated in  $\text{g}/\text{min}/\text{cm}^2$  as:  $m_{sw} = (\Delta H_2O)(AF)/(Rw \times A \times T)$  as originally described (Graichen et al. 1982). Segmented linear regression (Cheuvront et al. 2009; Vieth 1989) was sought to determine objectively the onset of local sweating. However, unlike the linear relationship  $m_{sw}/T_{es}$ ,  $m_{sw}/\text{time}$  was best fit by a horizontal baseline with an exponential association. The sweating onset time was therefore taken as the mathematical starting point for the exponential curve (Motulsky and Christopoulos 2003). A 30 s sampling rate was selected as this interval is well within the latency period that extends between sweat gland stimulation and sweat emergence (Bullard 1971). It also represents a fair tradeoff between sample frequency and sample noise (Cheuvront et al. 2009). Skin wettedness ( $w$ ) was calculated from the ratio of actual (saturated dew-point within the ventilated capsule,  $P_{s,dpl}$ ) to saturated skin vapor pressures ( $P_{s,sk}$ ) in relation to ambient vapor pressure ( $P_w$ ) as:  $w = [P_{s,dpl} - P_w]/[P_{s,sk} - P_w]$  (Gonzalez and Cena 1985). Local sweating measure were begun after 10-min of standing in the test environment to allow stable rest conditions. Steady-state sweating rate and skin wettedness were calculated from the final 5-min of exercise. The entire local sweating response was characterized by area under the curve (AUC) for local sweating

rate (SR), which was calculated using the trapezium rule [ $\Delta SR(t)/dt$ ] to characterize the entire local sweating response  $\times$  time.

Mean skin temperatures ( $T_{sk}$ ) were measured by thermistors (YSI, Yellow Springs, OH, USA) from four sites (forearm, chest, thigh and calf) and calculated using the equation:  $0.3 (T_{chest} + T_{forearm}) + 0.2 (T_{thigh} + T_{calf})$  (Ramanathan 1964). Measures of HR,  $T_{re}$ ,  $T_{sk}$ , thermal sensation (TS) (Gagge et al. 1971), and ratings of perceived exertion (RPE) (Borg 1970) were collected at min 0 and at each 10 min interval during the 30 min exercise bout. Physiological Strain Index (PSI) was calculated as:

$$PSI = 5(T_{ret} - T_{re0}) \times (39.5 - T_{re0}) + 5(HR_t - HR_0) \times (180 - HR_0)^{-1},$$

where  $T_{ret}$  and  $HR_t$  are simultaneous measurements taken at any time during exercise in the heat and  $T_{re0}$  and  $HR_0$  are the initial measurements (Moran et al. 1998). Sweat losses during heat acclimation and experimental testing with DEET were calculated as:

$$[\Delta \text{nude mass} - (UV + NSL)]/\text{time(h)},$$

where  $\Delta \text{nude mass}$  is the difference in nude body mass pre-to-post exercise, UV urine volume, NSL non-sweat losses, which include; respiratory water losses and  $CO_2$ – $O_2$  exchange (Consolazio et al. 1963). To calculate NSL, metabolic rate was measured from a 90-s sample of expired air approximately 20-min into each exercise bout using a computer-based metabolic system with continuous gas exchange measurements (Parvo Medics, Inc., Sandy, UT, USA).

#### Statistical analyses

The primary outcome variables of interest in this study were local (DEET<sub>LOC</sub>) and whole body (DEET<sub>WB</sub>) sweating and physiological responses to DEET application. Differences between local sweating measurements (rate, onset, skin wettedness) between trials (DEET<sub>LOC</sub> vs. CON) were investigated using paired *t* tests. The same analysis was used to compare the AUC calculations. Differences in HR,  $T_{re}$ ,  $T_{sk}$ , TS, and RPE between DEET<sub>WB</sub> and CON were compared over time using a two-way RM ANOVA. *F* values were adjusted for sphericity where appropriate, and main or interaction effects investigated by Newman–Keuls post-hoc test. Sample size was estimated from pilot testing on four volunteers. Local sweating responses of the forearm were measured on two separate occasions (8 observations) mimicking the exercise, heat acclimation status, and clothing configurations for the study. The day-to-day variation within-subjects was evaluated. The group within-subject standard deviation for sweating onset (0.93 min) and sweating rate (0.36 mg/cm<sup>2</sup>/min) were used

as an estimate of biological noise. We considered meaningful any DEET-related differences that were larger than the typical noise. Although this affords a large effect size ( $\geq 1.0$ ), it remains smaller than the differences observed in response to perturbations such as dehydration (Montain et al. 1995) or circadian rhythms (Stephenson et al. 1984). An analysis selecting conventional  $\alpha$  (0.05) and  $\beta$  (0.20) parameters showed that eight subjects would provide sufficient power to detect the desired effect. Similarly, this sample size is sufficient to detect a meaningful difference in  $T_{re}$  between DEET<sub>WB</sub> and CON, defined herein as a value larger than the typical standard deviation for  $T_{re}$  (0.25°C) (Consolazio et al. 1963). All data are presented as means  $\pm$  SD.

#### Results

All volunteers completed the 5-day heat acclimation protocol and all experimental and control trials. During exercise-heat exposure on day five, volunteers demonstrated classic physiological responses to repeated exercise-heat exposure including reductions in HR, and  $T_{re}$ , and increases in sweat rate and walk time to exhaustion, compared to day one (Table 1).

#### Sweating responses: DEET<sub>LOC</sub> versus CON

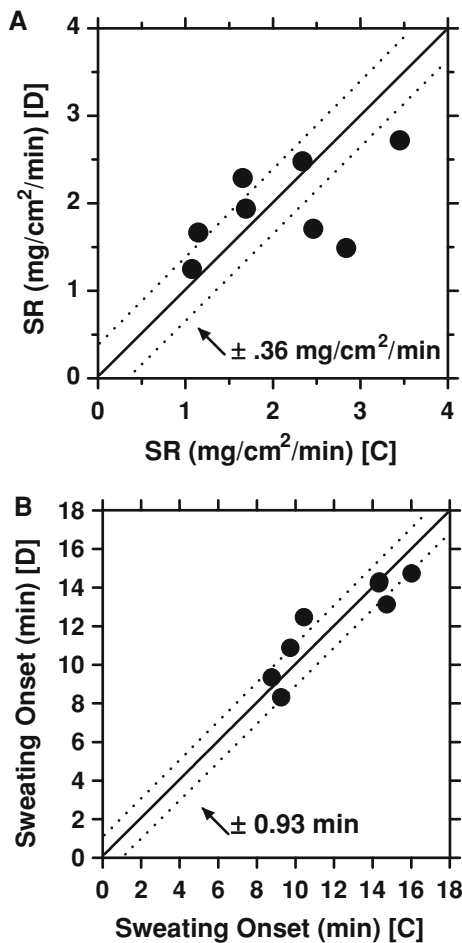
Due to an instrumentation problem, statistical analysis for local sweating responses was performed on eight, rather than nine volunteers. All other analyses are for  $n = 9$ . Figure 1 plots the individual DEET<sub>LOC</sub> versus CON trial data for sweat rate (SR; Fig. 1a) and sweating onset (Fig. 1b) against the line of identity and relative to biological noise for each measure. Figure 2a plots SR for DEET<sub>LOC</sub> versus CON over the last 10 min of standing rest and 30 min of walking exercise. There were no differences ( $p > 0.05$ ) in steady state SR between DEET<sub>LOC</sub> ( $1.89 \pm 0.44$  mg/cm<sup>2</sup>/min) versus CON ( $2.09 \pm 0.84$  mg/cm<sup>2</sup>/min)(Table 2). Figure 2b represents AUC analysis for SR of last 10 min of standing rest and 30 min of walking

**Table 1** Selected physiological adaptations to 5-day heat acclimation,  $n = 9$

|                                   | Day 1            | Day 5             |
|-----------------------------------|------------------|-------------------|
| Heart rate (HR; bpm)              | 147 $\pm$ 18     | 140 $\pm$ 15*     |
| Core temperature ( $T_{re}$ ; °C) | 38.27 $\pm$ 0.32 | 37.81 $\pm$ 0.22* |
| Sweat rate (L h <sup>-1</sup> )   | 1.11 $\pm$ 0.25  | 1.24 $\pm$ 0.26*  |
| Walk time to exhaustion (min)     | 87 $\pm$ 18      | 93 $\pm$ 12       |

Heart rate and  $T_{re}$  measures at min 30 of 100 min of exercise in the heat were compared

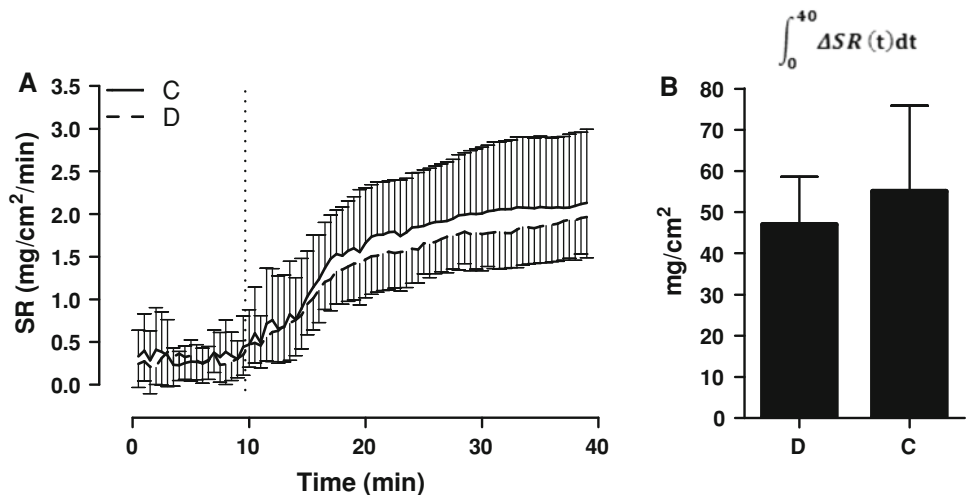
\* Significant difference ( $p < 0.05$ ) from Day 1



**Fig. 1** Individual DEET<sub>LOC</sub> (D) versus CON (C) trial data for sweat rate (SR; **a**) and sweating onset (**b**) against the line of identity and relative to biological noise (dotted lines) for each measure ( $n = 8$ , appears as  $n = 7$  due to overlapping values; mean  $\pm$  SD)

exercise. There were no differences ( $p > 0.05$ ) between SR AUC for DEET<sub>LOC</sub> ( $46.9 \pm 11.7 \text{ mg/cm}^2$ ) versus CON ( $55.0 \pm 20.8 \text{ mg/cm}^2$ ) trials (Table 2). In addition,

**Fig. 2** Sweat rate (SR; **a**) and SR area under the curve (AUC) histogram (**b**) for DEET<sub>LOC</sub> (D) versus CON (C) over the last 10 min of standing rest and 30 min of walking exercise ( $n = 8$ ; mean  $\pm$  SD). Dotted line in **a** indicates the start of exercise



sweating onset values between DEET<sub>LOC</sub> ( $12.2 \pm 2.9 \text{ min}$ ) and CON ( $12.2 \pm 2.4 \text{ min}$ ) and skin wettedness values between DEET<sub>LOC</sub> ( $66.5 \pm 20.3\%$ ) and CON ( $63.2 \pm 12.0\%$ ) were not different ( $p > 0.05$ ) (Table 2).

#### Physiological responses: DEET<sub>WB</sub> versus CON

Prior to, and throughout the 30 min walk in the heat, there were no differences ( $p > 0.05$ ) in HR,  $T_{re}$ ,  $T_{sk}$  (Fig. 3a–c) nor RPE and TS (Fig. 4a, b) between the DEET<sub>WB</sub> and CON trials. Metabolic rate was similar ( $p > 0.05$ ) between the DEET<sub>WB</sub> ( $1.8 \pm 0.3 \text{ L min}^{-1}$ ) and CON ( $1.9 \pm 0.3 \text{ L min}^{-1}$ ) trials. Gross whole body sweat rates calculated from pre- to post body mass measures were also not different ( $p > 0.05$ ) between the DEET<sub>WB</sub> ( $1.2 \pm 0.3 \text{ L h}^{-1}$ ) and CON ( $1.2 \pm 0.3 \text{ L h}^{-1}$ ) trials. PSI at the end of the 30 min walk in the heat was not different ( $p > 0.05$ ) between the DEET<sub>WB</sub> ( $4.9 \pm 0.8$ ) and CON ( $4.7 \pm 0.8$ ) trials, which is described as ‘Moderate’ strain (Moran et al. 1998).

#### Discussion

This investigation is the first to experimentally evaluate the potential impact of DEET insect repellent lotion on local and whole body thermal responses. We examined both local responses and whole body responses employing the administration recommended by the Department of Defense. Likewise, the metabolic rate employed is common for many military and occupational tasks (Pandolf et al. 1977). Based on topical protection and sun lotion studies (Gabaree et al. 1997; Spaul et al. 1985) and theoretical considerations, we hypothesized that the DEET lotion would impair measures of sweating and evaporation and therefore increase physiological strain and discomfort.

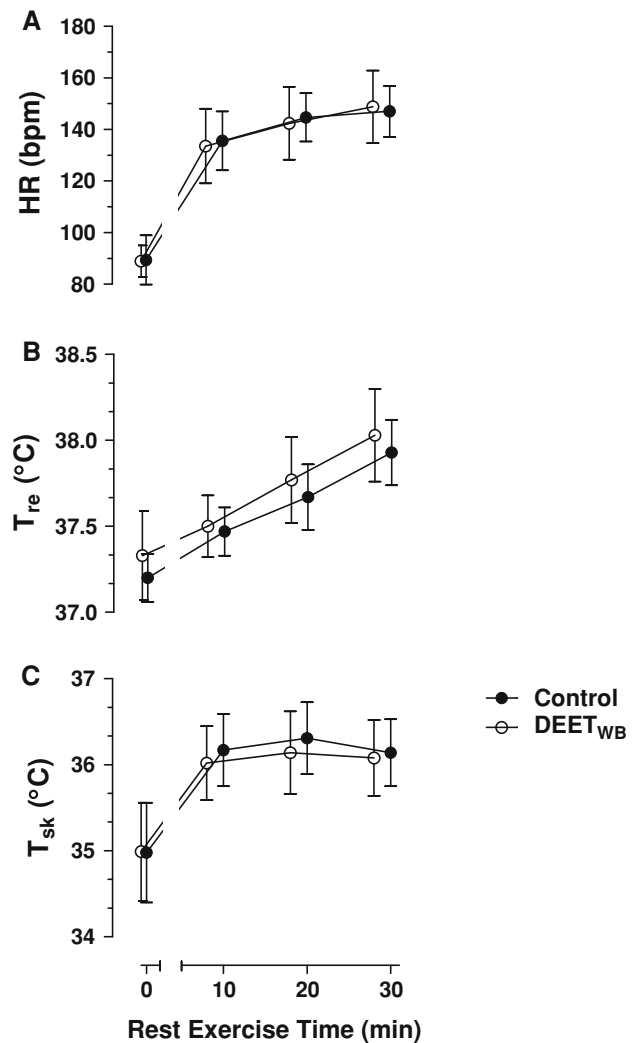
**Table 2** Local sweating responses, DEET<sub>LOC</sub> versus CON,  $n = 8$

|  | DEET <sub>LOC</sub> | CON         |
|--|---------------------|-------------|
| Sweating onset (min)                       | 12.2 ± 2.9          | 12.2 ± 2.4  |
| Steady state SR (mg/cm <sup>2</sup> /min)  | 1.89 ± 0.44         | 2.09 ± 0.84 |
| Area under the curve (mg/cm <sup>2</sup> ) | 46.9 ± 11.7         | 55.0 ± 20.8 |
| Skin wettedness (%)                        | 66.5 ± 20.3         | 63.2 ± 12.0 |

A caveat to our hypothesis was that due to the proprietary nature of the DEET formulation, the exact composition and the potential effects of the DEET lotion were unknown.

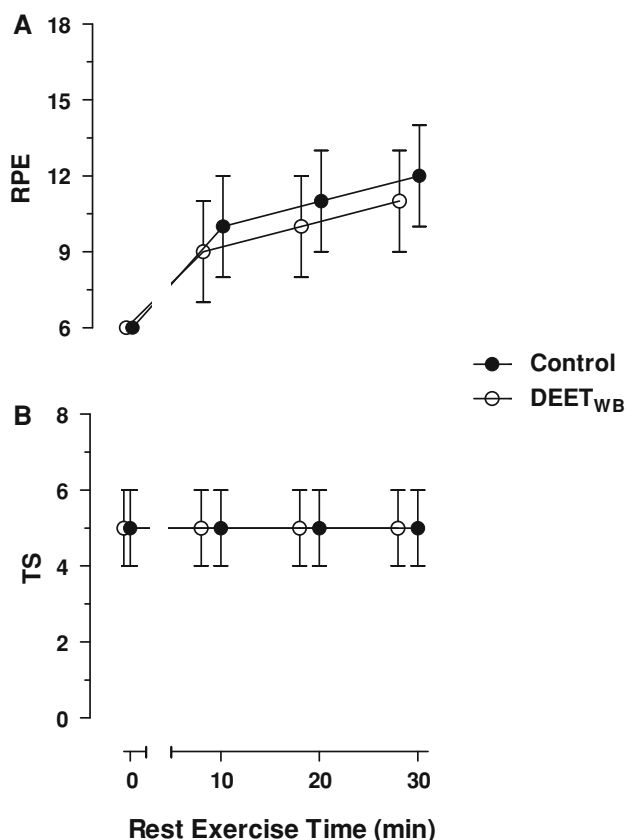
We observed no impact of 33% DEET lotion on local measures of sweating rate, onset, skin wettedness or TS, despite previous reports of ‘excessive heat’ (Spaul and Greenleaf 1984) or a loss of sweating sensation (McConnell et al. 1986) after DEET application. Examination of plots of sweat rate (Fig. 1a) and sweating onset (Fig. 1b), show that individual values were distributed evenly above and below the line of identity and for the most part, were within the biological noise of the measurements determined from pilot data. In addition, the comparison of AUC sweat rate (Fig. 2b) and comparison of skin wettedness revealed no impact of application of 33% DEET lotion. Only one other study that we are aware of has studied the impact of an insect repellent on local measures of sweating (Spaul et al. 1985). Spaul et al. (1985) observed the impact of both oil- and alcohol-based repellents spread ‘over 80% of the body’ on local measures of mean sweat rate of upper arm and forearm during 70 min of cycling exercise in ~44°C. They reported a significant increase in rectal temperature of ~0.2°C during the final 20 min of exercise in both the oil and alcohol repellants versus control, despite no differences in mean sweat rates. The authors state that the differences in rectal temperatures may have been due to a reduction sweat evaporation rate and not sweat production rate. We did not observe any differences in skin wettedness between DEET<sub>LOC</sub> and CON and both values were consistent with nearly 100% evaporative efficiency (Candas et al. 1979), contrary to the suggestion that repellent use could alter sweat evaporation rate. However, the repellents used in that study (Spaul et al. 1985) did not contain DEET and were described as either alcohol or oil based, which may be different from the DEET-based repellent used in the present study.

In regards to whole body gross measures of thermoregulation, we did not observe any impact of 33% DEET on HR,  $T_{re}$  or  $T_{sk}$  (Fig. 3a–c), or whole body sweat rates compared to the control trial. It has been suggested that heat gain could be altered by the use of TSPs and insect repellants by suppressing sweat formation by forming a barrier to evaporation (Connolly and Wilcox 2000; Gabaree et al. 1997; Spaul et al. 1985), or could depress eccrine sweating



**Fig. 3** Measures of HR (a),  $T_{re}$  (b), and  $T_{sk}$  (c) following 20-min of standing rest and 30-min of walking exercise in the heat for the DEET<sub>WB</sub> and CON trials ( $n = 9$ ; mean ± SD). Figure means are juxtaposed for presentation clarity

via hidromeiosis (Candas et al. 1979). One study on the impact of an alcohol based sun protectant on thermoregulation (Connolly and Wilcox 2000) reported significantly lower skin temperatures versus control in the first 5–10 min of exercise and a small reduction in body core temperature (0.1°C;  $p > 0.05$ ), attributed to the evaporation of alcohol in the product. Another investigation (Gabaree et al. 1997) studied the impact of a TSP applied to 21% of the BSA, during ~135 min of moderate intensity walking exercise in hot, humid conditions. They observed no effect of TSP on esophageal temperature, mean skin temperature, heart rate, exercise tolerance time, sweating rate or evaporative heat loss. There was, however, a non-significant average decrease in exercise time of 7 min while wearing the TSP. In addition, the authors reported a greater esophageal temperature rate of change during exercise between the TSP



**Fig. 4** Measures of RPE (**a**) and TS (**b**) following 20-min of standing rest and 30-min of walking exercise in the heat for the DEET<sub>WB</sub> and CON trials ( $n = 9$ ; mean  $\pm$  SD). Figure means are juxtaposed for presentation clarity

versus control trial, which they calculated would result in a  $\sim 0.5^{\circ}\text{C}$  greater esophageal temperature after 4 h of walking. However, similar to the findings of the present study, the authors concluded that the TSP used in the study had little to no effect on heat exchange.

In the present study, we did not observe any differences in ratings of perceived exertion or thermal sensation (Fig. 4a, b) between the whole body DEET and control trials. Gagge et al. (1969) demonstrated that the potential for thermal stimuli to produce sensory distraction was principally related to skin and ambient temperatures rather than body core temperature. In addition, one factor playing a role in the perception of effort are the sensations or feelings associated with cardiovascular strain (Pandolf et al. 1972). We did not observe any difference in heart rate or skin temperature between the whole body DEET and control trials (Fig. 3c), which may potentially explain why thermal sensations and RPE were not different (Fig. 4a, b). As previously mentioned, Connolly and Wilcox (2000) reported lower skin temperatures with the use of an alcohol-based sun protectant versus control in the first 10 min of exercise only. In addition, heart rate was not different during exercise in either trial nor did they observe

differences in RPE throughout either trial. Thus it would appear that 33% DEET used in the present study and some skin protectants (Connolly and Wilcox 2000) do not alter thermoregulation such that neither skin temperature nor heart rate was elevated and perceived exertion or thermal sensation was not altered.

Given the risk of disease associated with insect bites, the use of repellents is warranted for individuals who work outdoors or participate in outdoor sport/recreation in hot, insect infested environments. The use of 33% DEET lotion for protection against insect-borne illness is the recommended doctrine by the U.S. Military. Anecdote and survey reports suggested that individuals might feel alterations in the ability to sweat and a greater degree of heat gain with use of DEET repellent. However, we observed no impact of the application of 33% DEET lotion on local measures of sweating rate, onset, or skin wettedness, nor did we observe any alteration on measures of whole body thermoregulation, perceived exertion or thermal sensation using a militarily applicable model. It is important to note that numerous insect repellent products contain DEET in proprietary formulation with other components such as oils or alcohol which may, or may not interfere with thermoregulatory sweating. However, as local sweating and whole body thermoregulation did not appear to be altered by use of 33% DEET insect repellent lotion, it is unlikely to increase risk of heat illness/injury when used in a similar manner as the whole body application in the present study. These findings have importance given the increased use of DEET-based repellents in response to the rising incidence of insect-borne illnesses in the United States (e.g. Lyme disease, ehrlichioses, Eastern Equine Encephalitis) and worldwide (e.g. malaria, West Nile virus, dengue fever) (Institute of Medicine 2008). In addition, this information is important for any individual who uses DEET-based repellents in areas where there is a risk of insect-borne illness, including laborers, military personnel and outdoor enthusiasts.

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**Conflict of interest** None reported.

## References

- Berglund LG, Gonzalez RR (1977) Evaporation of sweat from sedentary man in humid environments. *J Appl Physiol* 42:767–772

- Borg G (1970) Perceived exertion as an indicator of somatic stress. *Scand J Rehabil Med* 2:92–98
- Bullard RW (1971) Studies on human sweat gland duct filling and skin hydration. *J Physiol (Paris)* 63:218–221
- Candas V, Libert JP, Vogt JJ (1979) Human skin wettedness and evaporative efficiency of sweating. *J Appl Physiol* 46:522–528
- Cheuvront SN, Carter R III, Montain SJ, Sawka MN (2004) Daily body mass variability and stability in active men undergoing exercise-heat stress. *Int J Sport Nutr Exerc Metab* 14:532–540
- Cheuvront SN, Bearden SE, Kenefick RW, Ely BR, Degroot DW, Sawka MN, Montain SJ (2009) A simple and valid method to determine thermoregulatory sweating threshold and sensitivity. *J Appl Physiol* 107:69–75
- Connolly DA, Wilcox AR (2000) The effects of an application of sunscreen on selected physiological variables during exercise in the heat. *J Sports Med Phys Fitness* 40:35–40
- Consolazio CF, Johnson RE, Pecora LJ (1963) Physiological variability in young men. In: *Physiological measurements of metabolic functions in man*. McGraw Hill, New York, pp 453–480
- DuBois EF (1916) Clinical calorimetry: a formula to estimate the approximate surface area if height and weight are known. *Arch Intern Med* 17:871–893
- Ely BR, Cheuvront SN, Kenefick RW, Sawka MN (2010) Aerobic performance is degraded, despite modest hyperthermia, in hot environments. *Med Sci Sports Exerc* 42:135–141
- Gabaree CL, Mair BS, Kolka MA, Stephenson LA (1997) Effects of topical skin protectant on heat exchange in humans. *Aviat Space Environ Med* 68:1019–1024
- Gagge AP, Stolwijk JAJ, Saltin B (1969) Comfort and thermal sensations and associated physiological responses during exercise at various ambient temperatures. *Environ Res* 2:209–229
- Gagge AP, Stolwijk JAJ, Nishi Y (1971) An effective temperature scale based on a simple model of human physiological regulatory response. *ASHRAE Trans* 77:247–262
- Gonzalez RR, Cena K (1985) Evaluation of vapor permeation through garments during exercise. *J Appl Physiol* 58:928–935
- Graichen H, Rascati R, Gonzalez RR (1982) Automatic dew-point temperature sensor. *J Appl Physiol* 52:1658–1660
- Institute of Medicine (2008) Vector-borne disease: emergence and resurgence. In: *Vector-borne diseases: understanding the environmental, human health, and ecological connections*. The National Academies Press, Washington, D.C. pp 41–126
- Jackson AS, Pollock ML (1978) Generalized equations for predicting body density of men. *Br J Nutr* 40:497–504
- Kenefick RW, Ely BR, Cheuvront SN, Palombo LJ, Goodman DA, Sawka MN (2009) Prior heat stress: effect on subsequent 15-min time trial performance in the heat. *Med Sci Sports Exerc* 41:1311–1316
- McConnell R, Fidler AT, Chrislip D (1986) NIOSH Health Hazard Evaluation Report Everglades National Park. Rep. No. HETA 83-085-1757
- Montain SJ, Latzka WA, Sawka MN (1995) Control of thermoregulatory sweating is altered by hydration level and exercise intensity. *J Appl Physiol* 79:1434–1439
- Moran DS, Shitzer A, Pandolf KB (1998) A physiological strain index to evaluate heat stress. *Am J Physiol* 275:R129–R134
- Motulsky H, Christopoulos A (2003) Fitting models to biological data using linear and nonlinear regression: a practical guide to curve fitting. Oxford University Press, New York
- Pandolf KB, Cafarelli E, Noble BJ, Metz KF (1972) Perceptual responses during prolonged work. *Percept Mot Skills* 35:975–985
- Pandolf KB, Givoni B, Goldman RF (1977) Predicting energy expenditure with loads while standing or walking very slowly. *J Appl Physiol* 43:577–581
- Ramanathan NL (1964) A new weighting system for mean surface temperature of the human body. *J Appl Physiol* 19:531–533
- Sawka MN, Wenger CB, Pandolf KB (1996) Thermoregulatory responses to acute exercise-heat stress and heat acclimation. In: Fregly MJ, Blatteis CM (eds) *Handbook of physiology*, section 4, environmental physiology. Oxford University Press, New York, pp 157–185
- Siri WE (1993) Body composition from fluid spaces and density: analysis of methods. *Nutrition* 9:480–491
- Spaul WA, Greenleaf JE (1984) Heat stress field study. *US Navy Med* 75:25–33
- Spaul WA, Boatman JA, Emling SW, Dirks HG, Flohr SB, Crocker WH, Glazeski MA (1985) Reduced tolerance for heat stress environments caused by protective lotions. *Am Ind Hyg Assoc J* 46:460–462
- Stephenson LA, Wenger CB, O'Donovan BH, Nadel ER (1984) Circadian rhythm in sweating and cutaneous blood flow. *Am J Physiol* 246:R321–R324
- Training and Doctrine Command (2007) Initial entry training soldier's handbook. TRADOC Pam 600-4
- Vieth E (1989) Fitting piecewise linear regression functions to biological responses. *J Appl Physiol* 67:390–396